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"Costs of Harvesting
Aspen Stands
For Energy Production"

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DSS Contract No. 42SS.KL015-0-0058

ENFOR PROJECT P-163

**"Costs of Harvesting
Aspen Stands
For Energy Production"**

Contractor

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Foreword

ENFOR is the bilingual acronym for the Canadian Forestry Service's ENERGY from the FOREST program of research and development aimed at securing the knowledge and technical competence to facilitate, in the medium to long term, a greatly increased contribution from forest biomass to our nation's primary energy production. This program is part of a much larger Federal Government initiative to promote the development and use of renewable energy as a means of reducing our dependence on petroleum and other non-renewable energy sources.

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... or the director of the establishment issuing this report.

This report, based on ENFOR Project P-163, was produced under contract (DSS File No. 42SS.KL015-0-0058) by The Coban Institute of Edmonton, Alberta. The conclusions of this report are the sole responsibility of The Institute and may not necessarily reflect the policies or views of the Government of Canada, its departments or agencies. Mention of brand names does not constitute an endorsement by the Government of Canada, its departments or agencies, in particular but not restricted to the Canadian Forestry Service.

The Institute wishes to thank Mr. W.J. Ondro of the Northern Forest Research Centre in Edmonton, Alberta for his excellent cooperation in his capacity as Scientific Authority for the project.

The Dika Side Cutter used for felling on this project was specifically designed and fabricated for this purpose by Michael Dika, Dika Construction Co. Ltd., Box 117, Rycroft, Alberta. Mr. Dika's useful suggestions and helpful advice were essential for the successful completion of the project.

Many people provided guidance and constructive criticism throughout the progress of the work. They include Jim Molnar, Alberta Forest Service, Hugh Stewart, Northern Forest Research Centre, Bud Finley, Alberta Research Council, Bill Varty, Varty Timber Products, Larry Jones, L.W. Jones Logging and Chipping, and Earl Jensen, Southview Fiber Tech. Ltd. Their contribution is gratefully acknowledged.

Special appreciation is expressed for the detailed review and comments provided by Brian Karaim, Alberta Forest Service, Terry Rachuk, Alberta Research Council and Ted Neumann, C.U. Engineering Limited on the final report.

All measurements presented in this report are in S.I. units.

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Abstract

The purpose of this report was to determine production and cost data which would assist resource managers to make rational decisions concerning the utilization of aspen for energy production.

Two aspen sites were selected on the Rocky Mountain House Grazing Reserve situated 30 km west of the town of Rimbey, Alberta. Site #1 contained 3.8 ha of 37 year old aspen; site #2 contained 4.9 ha of 58 year old aspen. The aspen was logged and chipped by the full tree harvesting system. Felling was carried out by chain saw and Dika Side Cutter. A Nicholson 22 Complete Tree Utilizer (C.T.U.) was used to chip the aspen.

The data indicated that it is unlikely that wood gas derived from full tree aspen chips will prove economically competitive with natural gas until 1983.

Résumé

Cette étude avait comme objectif d'établir les données sur la production et le coût de l'utilisation de peupliers pour la production d'énergie, afin d'aider ceux qui s'occupent de la planification de ressources forestières.

On a étudié des peuplements de 37 ans et de 58 ans situés dans la Rocky Mountain House Grazing Reserve à 30 km de distance de la ville de Rimbey, Alberta. Le peuplement de 37 ans avait 3.8 ha des peupliers tandis que le peuplement de 58 ans avait 4.9 ha des peupliers. On a fait l'abattage manuel et mécanisé des arbres entiers. Ensuite on les a transportés jusqu'à un dépôt d'embarquement où on les a empilés. À la fin de l'abattage on les a transportés dans des camions à un dépôt central où on les a broyés par une machine Nicholson 22 Complete Tree Utilizer (C.T.U.).

Les données indiquent qu'il est peu probable que le gaz d'arbre soit aussi économique que le gaz naturel jusqu'à 1983.

Introduction

Statistics provided by the Alberta Forest Service (A.F.S.) indicate that Alberta's 16 million ha of productive forest land contain 1.7 billion m³ of wood (ENR, 1968). Softwoods (spruce, pine, fir and larch) account for 1 billion m³ and hardwoods (poplar and birch) account for the remaining volume of 0.7 billion m³. A.F.S. figures suggest that this forested land will support an annual production of 14 million m³ of softwoods and 13.5 million m³ of hardwoods.

The above volumes do not reflect the total biomass available because they do not include estimates of the foliage, branches and tops that remain after logging merchantable trees nor do they allow for estimates of non-marketable trees of all species and sizes. When these "biomass correction factors" are applied the volume increases by a factor between 130-230 percent (Karaim, 1978).

In 1978 the Alberta annual production of softwoods was 6.5 million m³ or 46 percent of the annual allowable cut, while only 6.4 thousand m³ or 0.05 percent of the annual allowable cut of hardwoods was harvested (ENR, 1979).

One important constraint barring more extensive aspen utilization is the economics of logging (Jones, 1977). Much of the hardwood forest in Alberta is composed of mature and over-mature stands. It is not uncommon for cull and decay in these stands to exceed 55 percent (Bailey, 1977). Unfortunately, much of this decay cannot be detected until the tree is shipped to a processing mill where, upon further processing, it is found to be unmerchantable. On a recovery basis, this results in very high logging costs and discourages the utilization of aspen for conventional products. However with rising energy prices there has been a renewed interest in these hardwood stands as a potential source of biomass for energy production.

The Coban Institute's interest in using aspen for energy production stemmed from a preliminary investigation by staff in the compression engineering section of NOVA, AN ALBERTA CORPORATION into the technical feasibility of using methanol produced from forest biomass to fuel gas turbines at company compressor stations (Dunn, 1981). Methanol was considered to be an ideal turbine fuel because of its clean burning characteristics which could lead to lower pollutant emission and longer engine life.

Initial studies indicated that it was not necessary to go the full route to methanol

synthesis because gas turbines would be capable of running on a 50/50 mixture of natural gas and low kJ gas (100-150 kJ/ft³) produced from wood (Seglem & DeCorso, 1980). Although this low kJ wood gas would have to be cleaned of some contaminants, other gas constituents such as nitrogen and water could remain in the gas stream because the high mass flow rate of the turbine would tend to maintain overall engine efficiency.

The potential market for this type of low kJ gas is extensive. There are approximately 70,000 miles of gas pipelines in Alberta. The 3,000 plus compressor stations located along this pipeline system range in size from 225 to 26 000 kW. Over 50 percent of these compressor stations are situated near large stands of aspen.

Based on a 50/50 mixture of natural gas and low kJ gas, one 22 500 kW compressor unit with a heat rate of 8 000 kJ/kW hour running for 70 percent of the year (6130 hours) would use 15 billion cubic feet of low kJ gas per year or the energy equivalent of 78 000 oven-dry tonnes (ODt) of aspen. This represents a saving of approximately 1.5 billion cubic feet of natural gas or enough natural gas to heat 7,600 Canadian homes for one year.

The cost of the raw material is an essential element in the economic analysis of the potential of using aspen as a source of fuel to generate low kJ gas for gas turbines.

The objective of the present project was to determine the costs per oven-dry tonne of harvesting aspen under variable stand conditions.

Project discussions started in June 1980. Work sites were selected in November 1980. Contract preparation was completed in January 1981. Project work commenced in February 1981 with the sites being classified and inventoried. Logging operations started in the last week of February, followed by chipping operations the third week in March. Local contractors were used for most phases of the work. The chipping equipment came from Rochester, Washington. Field operations were completed by the end of March. Data analysis was carried out during May and June.

Conclusions reached were based on data collected during field operations and on general impressions gained from observing and working with the harvesting equipment on a day to day basis.

No attempt was made to identify silvicultural management problems that might be associated with the type of felling equipment used on the project. An assessment of the project's environmental impact on wildlife in the area was also excluded. Each of these concerns should receive high priority in the development of any comprehensive, well-coordinated plan for the utilization of aspen as an energy source.

Scope and Objectives

The scope of this report was to:

1. Select and compare harvesting equipment for the efficient logging and chipping of aspen.
2. Determine the productivity and costs of harvesting aspen under variable stand conditions.
3. Establish the relevant physical properties of aspen chips in order to assess their value as an energy source for generating low kJ gas.

Within the scope the following specific objectives were to:

- Select two aspen sites, one approximately 30 years old and the other approximately 70 years of age.
- Determine the quantity of aspen on each of the sites and to prepare average stand and stock tables.
- Log and chip aspen on each of the sites using the full tree harvesting system.
- Determine the unit cost per tonne on an oven-dry basis of harvesting aspen on each of the sites.
- Establish the energy value of aspen as a function of the cost per 10^9 J.
- Compare the energy value of aspen with the energy value of natural gas and establish the cost differential.
- Prepare an information report describing the harvesting operations carried out in the project.

Summary

Two stands of trembling aspen (*Populus tremuloides*) near Rimbey, Alberta were logged and chipped using the full tree harvesting system as a further step in evaluating the potential use of aspen for energy production. All phases of the harvesting operation including felling (chain saw and Dika Side Cutter), skidding, trucking and chipping were monitored to determine productivity and cost data over a period of two months in 1981.

Harvesting operations on sites #1 and 2 recovered 85 percent and 90 percent respectively, of the total amount of biomass available for utilization. These volumes indicate a significant improvement in fibre production over those volumes that are produced under current shortwood and tree length harvesting systems.

The productivity of the Dika Side Cutter on sites #1 and 2 was 1030 percent and 1385 percent higher than for the chain saw. Chain saw felling yielded costs on sites #1 and 2 of \$4.30/ODr and \$2.50/ODr. Felling on sites #1 and 2 using the Dika Side Cutter mounted on a D8K tractor resulted in a cost of \$0.60/ODr.

The productivity of skidding aspen felled by the Dika Side Cutter on sites #1 and 2 was 25 percent and 15 percent higher than for skidding aspen felled by chain saw on sites #1 and 2. The costs of skidding aspen felled by chain saw on sites #1 and 2 were \$35.00/ODr and \$10.00/ODr. The costs of skidding aspen felled by the Dika Side Cutter on sites #1 and 2 were \$28.00/ODr and \$8.75/ODr.

Loading aspen harvested from sites #1 and 2 yielded costs of \$5.35/ODr and \$6.65/ODr. Trucking aspen harvested from sites #1 and 2 resulted in costs of \$1.70/tonne-kilometre (t-km) and \$1.30/t-km. The costs of trucking from sites #1 and 2 adjusted for distance were \$11.75/ODr and \$17.15/ODr. Unloading aspen harvested from sites #1 and 2 resulted in costs of \$1.40/ODr and \$1.10/ODr.

Chipping aspen from sites #1 and 2 was carried out by a Nicholson 22 C.T.U. and resulted in a cost of \$12.90/ODr.

Harvesting aspen felled by chain saw on site #2 was 30 percent more cost effective than harvesting aspen by chain saw on site #1. Harvesting aspen felled by the Dika Side Cutter

mounted on a D8K tractor on site #2 was 21 percent more cost effective than harvesting aspen by the Dika Side Cutter mounted on the same machine on site #1. These figures indicate that tree size was the primary variable in determining unit costs for all phases of the harvesting operation. This finding is typical of all types of harvesting systems.

By altering the configuration of the harvesting system developed and tested on this project it is estimated that aspen on site #1 felled by the Dika Side Cutter could be delivered at a cost of \$21.08/ODr. The energy equivalent value of this aspen would be \$1.10/10⁹ J. Based on the capital and operating costs of a 64 x 10⁶ J/hr Higher Heating Value (HHV) wet gas fluidised bed gasifier, the life-cycle costs for gasification, cleaning and compression would increase this cost to \$2.44/10⁹ J. The current price of natural gas is \$1.70/10⁹ J (Alberta Petroleum Marketing Commission, September/1981). On strictly a dollar per unit of energy basis and accepting the September 1981 Ottawa-Alberta energy agreement at face value, it is unlikely that wood gas derived from full tree aspen chips will prove economically competitive with natural gas until 1983.

No substantial differences in density, moisture content and heating value were observed between samples of aspen chips from sites #1 and 2.

Methodology

Site Selection:

Discussions regarding siting requirements for ENFOR Project P-163 were held with officials from the A.F.S. in the fall of 1980. At that time A.F.S. had already planned to clear cut approximately 1000 acres of aspen on the Rocky Mountain House Grazing Reserve situated 30 km west of the town of Rimbey, Alberta. The Reserve is located in the R1 management unit of the Rocky-Clearwater Forest. A.F.S. officials offered to provide access to the Reserve if suitable aspen could be found to meet the objectives of the project.

Three work sites were selected (Figures 1, 2, 3). Site #1 situated on Section 14, Township 43, Range 6, West of the 5th Meridian contained a stand of 37 year old aspen. Site #2 situated on Section 29, Township 42, Range 5, West of the 5th Meridian contained a stand of 58 year old aspen. The area of site #1 was 3.8 ha while the area of site #2 was 4.9 ha. A third site to serve as a storage and chipping area was selected adjacent to Highway 53 approximately 6.9 km west of site #1 and approximately 13.2 km west of site #2.

Site Description:

Highway 22 provides all weather access to the sites north from the town of Rocky Mountain House. Similar access is available on Highway 53 west from the town of Rimbey. The sites are in close proximity to a number of pipeline compressor stations which would be suitable for experimentation with low kJ gas.

Topography of the sites is undulating to hilly with 55 percent of the slopes in the 5 to 9 percent range and 45 percent of the slopes in the 9 to 15 percent range (Alta. S.S. Report #24, 1968).

Situated in the Boreal Forest Region, Aspen Grove Section (Rowe, 1972), the tree cover on the sites is primarily trembling aspen (*Populus tremuloides* Michx.) in the better drained areas and balsam poplar (*Populus balsamifera* L.) in the poorly drained areas (Figures 4, 5). Willow (*Salix* L.) is found on the wetter areas. Grass cover is primarily rough fescue (*Festuca scabrella*). The sites contain depressions that are covered by peat. The depth of this peat varies from 30 cm to over 75 cm. Labrador tea (*Ledum groenlandicum*) is the principal shrub growing on these bogs with dwarfed birch (*Betula occidentalis* Hook.) growing around the edges.

Climatic conditions are characterized by warm summers and cold winters. Annual mean temperature is approximately 2.7° C with January being the coldest month having a mean of -13.8° C and July being the warmest month having a mean of 15.5° C. Annual mean precipitation ranges from 430 to 500 mm with 60 percent of this amount falling during May to August. About one quarter of the precipitation falls during the winter months. The number of frost free days is estimated to be in the range of 60 to 75 days.

Soil is imperfectly to well drained and is classified as grey and dark grey wooded. Deciduous leaf litter and grass usually comprise the first 6 to 8 cm of this soil with approximately 21 to 23 cm of pale brown silt loam lying below this surface layer. Horizons of dark greyish brown clay extend downward for another 220 to 230 cm.

Inventory Techniques:

In early February of 1981 staff of the Northern Forest Research Centre conducted an inventory on sites #1 and 2. Line plots were established and all standing trees were measured and recorded from twelve plots in site #1 and eighteen plots in site #2. Average stand and stock tables were then prepared (Appendix A-1). Cull and decay in the aspen on these two sites did not exceed 10 percent by volume. Average Diameters Breast Height (D.B.H.) of trees for site #1 and 2 were 18 cm and 30 cm respectively.

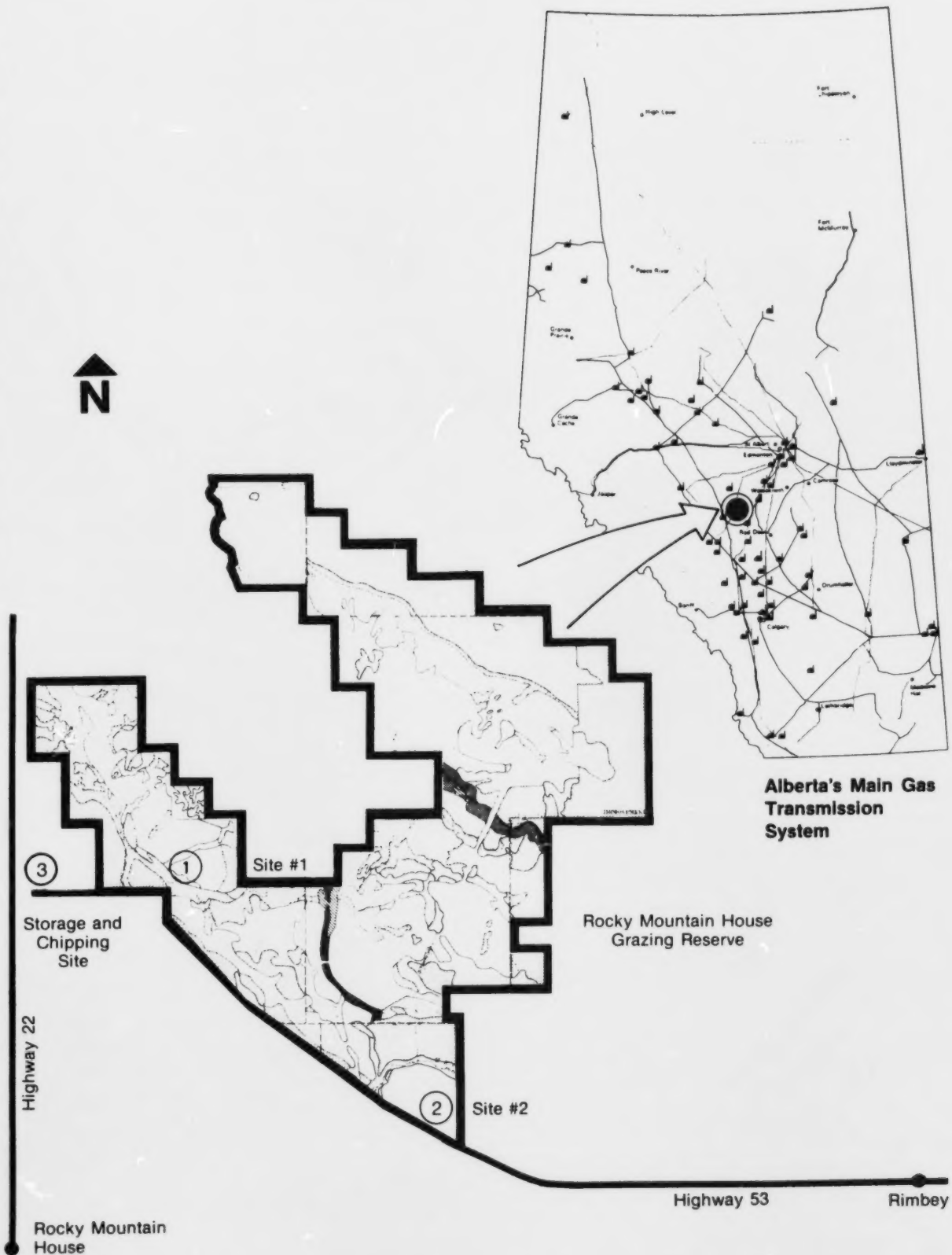


Figure 1. Location of work sites.

Logging And Chipping Procedures:

Based on the form in which the wood arrives at the landing, McNally (1977) classifies harvesting systems as: a) shortwood; b) tree length; or c) full tree. In the shortwood system, trees are reduced to short lengths (up to 2.5 m) at the felling site and then transported to the landing. The tree length system involves the trees being felled, limbed and topped at the felling site and then skidded to the landing for cutting to desired lengths or direct shipment to the processing mill. In the full tree system the tree is felled and the entire above ground portion transported from the felling site to the landing where it is delimbed and topped.

According to McNally, 16.4 percent of the wood produced by the member companies of the Canadian Pulp and Paper Association is produced by the shortwood system; 68.3 percent by the tree length system and 15.3 percent by the full tree system.

For the purposes of this project it was decided to extend the full tree harvesting concept to include delivery of the entire tree minus stump, roots and twigs directly to a central storage and chipping site. This procedure would ensure the completion of the chipping phase of the harvesting operation in the event of an early spring breakup on the two logging sites.

In site #1, approximately one half of the area was clear cut by a Stihl 048 AV chain saw with a 53 cm bar and the other half clear cut by a 4.2 m wide Side Cutter manufactured by Dika Construction Co. Ltd. of Rycroft, Alberta (Appendix A-2). A similar clear cutting operation was carried out on site #2.

Aspen felled on these two sites was skidded to landings by a John Deere 540-B cable skidder and cold decked. A Hough 80 log loader was used to load the aspen onto trucks for transportation to the storage and chipping area west of the logging sites. At the storage and chipping site the trucks were weighed and then unloaded by a John Deere 450-C log loader. A Hough 80 log loader was used to feed the aspen to a Nicholson 22 C.T.U. to complete the harvesting operation.

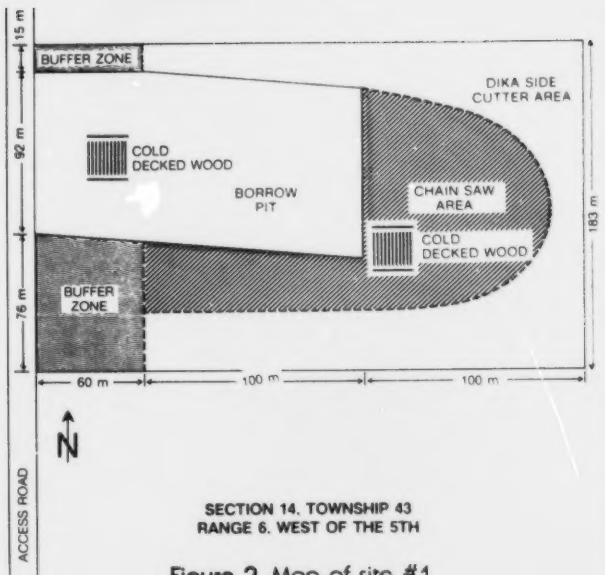


Figure 2. Map of site #1

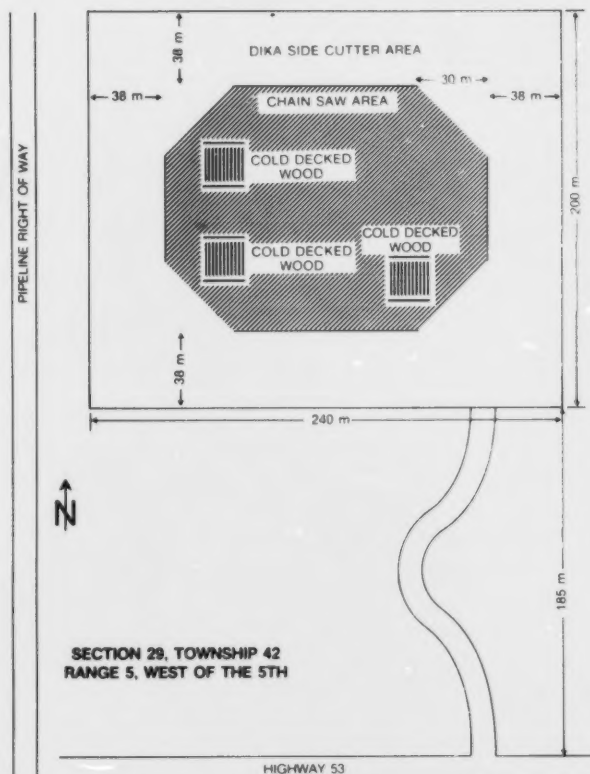


Figure 3. Map of Site #2



Figure 4. Prelogging conditions site #1

Study Procedures:

All phases of the harvesting operation were timed. The span of time it took to fell trees by chain saw on both sites was measured. The time span taken to cover specified distances by the Dika Side Cutter while in a harvesting mode was also measured.

The turn around time which included attaching chokers, tightening cable, travelling to landing, detaching chokers, straightening pile and returning was likewise measured for the skidding phase on both sites. Time lapses were also recorded for loading at landing, transporting to truck scale, weighing, unloading, reweighing and returning to the landing. In the chipping phase the time required by the hydraulic operated log boom to place the aspen into the self-feeding conveyor system was measured as was the time required for the trees to reach the chipping knives.

Cumulative time records were kept for all phases of the harvesting operation including downtime for maintenance and repairs. The average time for each phase was calculated.

Production And Cost Analysis:

Inventory data were used to determine volumes in m^3 . The weight of all aspen harvested from the sites was recorded. The average time and weight were used to calculate Productive Machine Hour (PMH). The cost per oven-dry tonne for all phases of the harvesting operation was then computed.

Laboratory Analysis:

Samples of the aspen chips were collected in plastic bags to prevent moisture loss and immediately transported to laboratory facilities where moisture content and calorific value on an oven-dry basis were measured. Bags were labeled to identify the site and the type of material.



Figure 5. Prelogging conditions site #2

Observations

Felling By Chain Saw:

This phase of the harvesting operation was carried out by a single worker using a Stihl 048AV chain saw with a 53 cm bar (Figure 6). A standard 8 hour shift starting at 08:00 hrs and finishing at 16:30 hrs with a 30 minute lunch break and two 10 minute coffee breaks was followed each day throughout the felling phase.

Analysis of the data collected during this phase indicated that the productivity on site #1 and 2 was 3.5 ODr/PMH and 6.0 ODr/PMH, respectively. The total aspen felled by chain saw on site #1 and 2 was 128.0 ODr and 201.0 ODr.

The worker was contracted at a rate of \$15.00/hr. This rate included equipment costs of \$3.20/hr and wages and fringe benefits of \$11.80/hr. The cost of felling aspen by chain saw on sites #1 and 2 was \$4.30/ODr and \$2.50/ODr.

Site conditions during this phase were generally fair to good because of a mild winter with little snow. The temperatures ranged between 0° and 7° C during the day.

Refueling at the sites occurred on the average of 3 times per shift. Down time for repairs to the chain saw was minimal.

Felling By The Dika Side Cutter:

The Dika Side Cutter was initially mounted on the front of a D8H Caterpillar tractor. However the D8H tractor with an engine power of 175 kW lacked the power to maintain a constant ground speed when cutting trees over 25 cm D.B.H.

The Side Cutter was designed to shear trees off at ground level and directionally fall them in a swath at a 45° angle to the tractor. The pressure bar located at the top of the Side Cutter was designed to exert pressure on the trees as they were being cut and to assist in directing their fall. As the D8H tractor moved against trees in excess of 25 cm D.B.H. it would begin to lose ground speed. This loss of power reduced the effectiveness of the pressure bar and resulted in the Side Cutter laying a tangled swath. This type of swath made the task of attaching skidder chokers very difficult. The D8H tractor was replaced with a D8K tractor with an engine power of 224 kW (Figure 7). This additional power was sufficient to maintain a constant cutting speed of

approximately 9.0 km/hr on site #1 and approximately 7.0 km/hr on site #2. This constant cutting speed provided a consistent tree falling direction.

Analysis of the data collected on this phase of the harvesting operation indicated that the productivity for the Dika Side Cutter on sites #1 and 2 was 39.5 ODr/PMH and 89.0 ODr/PMH. The total aspen felled by the Side Cutter on sites #1 and 2 was 136.5 ODr and 215.0 ODr.

The total aspen felled by chain saw and the Dika Side Cutter on sites #1 and 2 is summarized below.

Table 1
Productivity (t)*

Activity	Location	
	Site #1	Site #2
Chain Saw	128.0	201.0
Dika Side Cutter	136.5	215.0
Total	264.5	416.0

*Note: oven-dry tonne

The D8K tractor operator was hired at a rate of \$130.00/hr. This rate included costs of \$116.00/hr for the tractor and Dika Side Cutter and wages and fringe benefits of \$14.00/hr. The cost of felling by the Dika Side Cutter on sites #1 and 2 using the D8K tractor was \$0.60/ODr.

Site conditions for the Dika Side Cutter were the same as those described for the chain saw felling phase. No mechanical delays were encountered during this phase of the operation, although several work stoppages totalling 2 hours occurred on site #2 when an accumulation of twigs and small branches around the engine compartment posed a potential fire hazard and had to be removed.



Figure 6. Felling aspen by chain saw



Figure 7. Felling aspen with Dika Side Cutter

Skidding:

Skidding was carried out by a single John Deer 540-B cable skidder with an engine power of 72 kW (Figure 8). The skidder used a 4.0 cm cable with 10, 1.3 cm chokers. The skidder operator and two chokermen worked a standard 8 hour shift starting at 08:00 hrs and finishing at 16:30 hrs. A 30 minute lunch break and two 10 minute coffee breaks were taken each day throughout the skidding phase.

Analysis of the data collected on the skidding phase indicated that the productivity of skidding aspen felled by chain saw on sites #1 and 2 was 2.0 ODr/PMH and 7.0 ODr/PMH. The productivity of skidding aspen felled by the Dika Side Cutter on sites #1 and 2 was 2.5 ODr/PMH and 8.0 ODr/PMH.

The skidder contractor was hired at a rate of \$70.00/hr. This rate included equipment costs of \$35.00/hr and wages and fringe benefits of \$13.00/hr for the skidder operator and \$11.00/hr for the chokermen. The costs of skidding aspen felled by chain saw on sites #1 and 2 were \$35.00/ODr and \$10.00/ODr. The costs of skidding aspen felled by the Dika Side Cutter on sites #1 and 2 were \$28.00/ODr and \$8.75/ODr.

Site conditions for the skidding phase were good until mid March. From that time on the warmer temperatures caused site conditions to

deteriorate by early afternoon. However no serious rutting occurred and productivity did not appear to have been affected.

The only major work stoppage of 8 hours occurred during the skidding phase when a metal oil line on the skidder ruptured. Repairs to chokers were minimal.

Transportation:

Aspen was loaded onto trucks at the sites by a Hough 80 log loader with a Welco #20 log grapple (Figure 9). The engine power of this machine is 140kW and has a lifting capacity of 4048 kg. Two Pacific logging trucks and one Kenworth with a high boy trailer were used for the 6.9 km haul from site #1 and the 13.2 km haul from site #2. A John Deere 450-C log loader was used at the central storage and chipping site to assist in the unloading. The engine power of this machine is 52 kW while the lifting capacity is 3515 kg.

A Mantle 23030 P.V. truck scale was used at the central storage and chipping site to weigh all loaded and empty trucks travelling to and from the logging sites (Figure 10). The scale is 9.2 m in length and has a capacity of 27 200 kg. All trucks were weighed on the single front axle and rear tandem axles of the tractor and the rear tandem axles of the trailer to determine gross, tare and net weights.



Figure 8. Skidding aspen to landing

Analysis of the data collected on the transportation phase indicated that the productivity of loading aspen on sites #1 and 2 was 15.5 ODr/PMH and 12.5 ODr/PMH. Return trip time for trucking from sites #1 and 2 averaged 1.12 hrs and 1.82 hrs. Load size from sites #1 and 2 averaged 7.15 ODr and 8.00 ODr. The productivity of unloading aspen from sites #1 and 2 was 32.5 ODr/PMH and 41.5 ODr/PMH.

The Hough 80 log loader was contracted at a rate of \$83.00/hr. This rate included equipment costs of \$70.00/hr and wages and fringe benefits of \$13.00/hr. The trucks were hired at a rate of \$75.00/hr. This rate included equipment costs of \$62.00/hr and wages and fringe benefits of \$13.00/hr. The John Deere log loader was hired at a rate of \$45.00/hr. This rate included equipment costs of \$32.00/hr and wages and benefits of \$13.00/hr.

Loading aspen harvested from sites #1 and 2 yielded costs of \$5.35/ODr and \$6.65/ODr. Trucking aspen harvested from sites #1 and 2 resulted in costs of \$1.70/tonne-kilometre (t-km) and \$1.30/t-km. The costs of trucking from sites #1 and 2 adjusted for distance were \$11.75/ODr and \$17.15/ODr. Unloading aspen harvested from sites #1 and 2 resulted in costs of \$1.40/ODr and \$1.10/ODr.

Trucking statistics are summarized in the following table.

Table 2
Trucking Statistics (t)*

Economic Criteria	Location	
	Site #1	Site #2
Average Load Size (t)	7.15	8.00
Loaded Haul Distance (km)	6.90	13.20
Tonne-km	49.35	105.60
Return Trip Time (Hr)	1.12	1.82
Cost \$/t-km	\$ 1.70	\$ 1.30
Cost \$/t	\$11.75	\$ 17.15

*Note: oven-dry tonne

Transportation conditions were generally good until mid March. Beginning at this time the trucks were forced to haul from 05:00 hrs to 12:00 hrs in order to keep the approaches to both sites from becoming too rutted. They had originally been hauling from 08:00 hrs to 17:00 hrs. Drivers were also forced at this time to chain up to navigate the grade into site #2. On March 10 all trucks had to reduce their pay load by 40 percent to meet local road ban restrictions. This factor inflated the unit cost per tonne for trucking aspen from sites #1 and 2 by \$2.43/ODr and \$5.62/ODr.



Figure 9. Loading aspen at landing

Chipping:

The chipping was carried out by a Nicholson 22 C.T.U. (Figure 11). This machine has an engine horsepower of 392 kW. The chipping unit has a 56 cm spout and 6 knives mounted on a V-Drum chipper. The aspen was placed on the chipper's 107 cm infeed conveyor by a 7.3 m hydraulic boom with a 2 500 kg lifting capacity. The chipping unit with tractor weighed approximately 39 000 kg. The Hough 80 log loader was used to feed the chipper.

The chipper was started at 08:00 hrs and allowed to warm up for 30 minutes each day. The machine was shut down at 17:00 hrs each day. A 30 minute lunch break and two 10 minute coffee breaks were taken each day throughout the chipping phase.

Analysis of the data collected on the chipping phase indicated that the productivity of chipping aspen from sites #1 and 2 was 19.0 ODt/PMH. Productivity statistics for all phases of the harvesting operation are summarized in Table 3.

The chipping contractor was hired at a rate of \$162.00/hr. This rate included equipment costs of \$144.00/hr and wages and fringe benefits of \$18.00/hr. The cost of aspen chipped from sites #1 and 2 was \$12.90/ODt.

Site conditions for the chipping phase were favourable. Temperatures averaged 5° C during

Table 3
Productivity (t/PMH)*

Activity	Location	
	Site #1	Site #2
Felling (chain saw)	3.5	6.0
Skidding (chain saw)	2.0	7.0
Felling (Side Cutter)	39.5	89.0
Skidding (Side Cutter)	2.5	8.0
Loading	15.5	12.5
Unloading	32.5	41.5
Chipping	19.0	19.0

*Note: oven-dry tonne

the day with no precipitation. The site was well drained; consequently, all machines had good footing. Productivity was lower on occasion when chipping aspen from site #2 since some of the butts of the larger trees exceeded the 56 cm spout on the chipper. These butts were subsequently removed by chain saw. An estimated 30 trees required this type of treatment.

There were relatively few work stoppages. A broken link in the infeed conveyor of the chipper resulted in a down time of approximately 1.5 hours. Repairs to the hydraulic boom resulted in a down time of approximately 1.0 hours. This level of availability (93 percent) for a 3 year old wood chipper reflects an excellent maintenance schedule exercised by the chipping contractor.

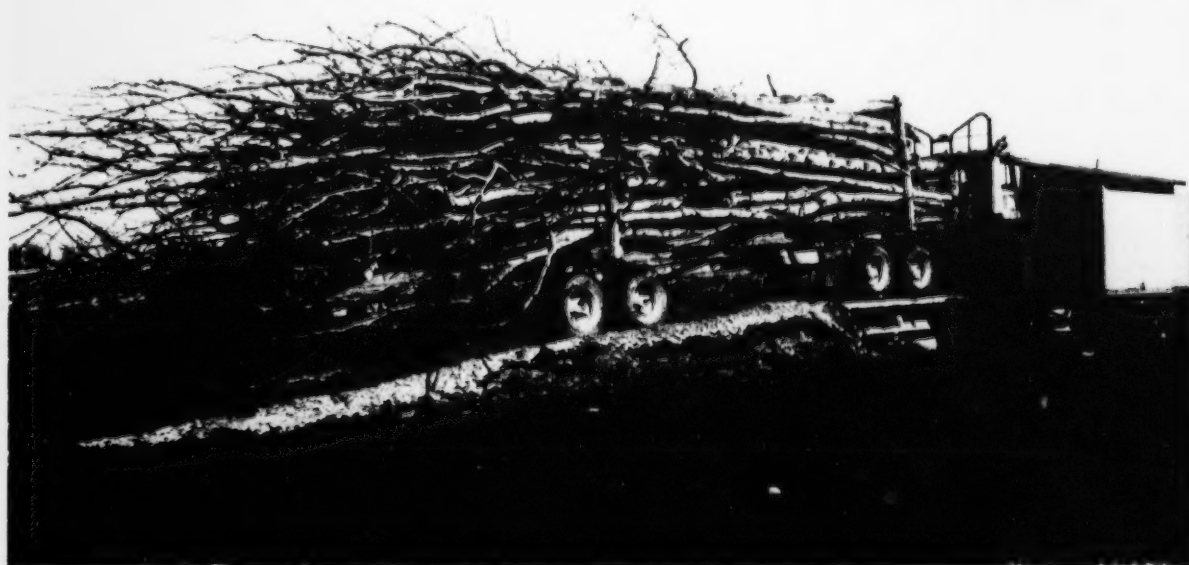


Figure 10: Weighing aspen at truck scale

Aspen Chip Specifications:

The grading system used by the two bleached kraft pulpmills in Alberta is the Williams Chip Classification System. It incorporates the size of chips, moisture content and amount of fines. Aspen chip samples from the two sites were analyzed according to this system by staff at the Proctor & Gamble pulpmill situated near Grande Prairie, Alberta. The results were summarized below.

Table 4
Aspen Chip Size Distribution (cm)*

Screen Size	5.0	3.0	2.5	1.5	1.0	0.5	Fines	Bark
Percentage Retained	00.00	10.64	15.97	34.74	30.71	5.88	2.06	9.45

*Note: Williams Classification System

One set of knives on the chipper was used for the entire chipping period. As these knives gradually lost their edge a greater variation in chip size was observed. However, most of the aspen chips were still of an acceptable size limit for existing fuel handling systems common to most commercial wood burning installations (Archibald, 1976).

Aspen chip samples from both sites were analyzed for moisture, density and heating value. The results are summarized below.

Table 5
Laboratory Analysis*

Sample #	Moisture Content (percent of total weight)	Bulk Density (g/ml)	Heating Value (J/kg)
1	44.2	0.159	19 079.1
2	47.7	0.163	19 236.0
3	48.4	0.184	19 254.8

*Note: oven-dry basis

Average density for all samples was 0.161 g/ml. The average moisture content was 46.8 percent while the average heating value was 19.2×10^3 J/kg on an oven-dry basis. There was no significant variation in these values between sites.



Figure 11. Chipping with Nicholson 22 C.T.U.

Conclusions

In terms of the objectives set out at the beginning of this report the following conclusions can be drawn:

Total amount of biomass available for harvest on sites #1 and 2 calculated from total above-ground component weight equations (Bella et al, 1980) was 81.0 ODt/ha and 95.0 ODt/ha, respectively. Full tree harvesting of aspen from sites #1 and 2 recovered 69.5 ODt/ha and 84.5 ODt/ha (85 percent and 90 percent respectively, of the total amount of biomass available for utilization). Total residual biomass left after harvesting on sites #1 and 2 was 11.5 ODt/ha and 10.5 ODt/ha (Figures 12, 13). The volumes produced by the full tree harvesting system indicate a significant improvement in utilization over those volumes recovered under current shortwood and tree length harvesting systems. According to Woodard, (1973), conventional 'cut and skid' operations in hardwood stands seldom remove more than 50 percent of the available biomass.

The productivity of the Dika Side Cutter on sites #1 and 2 was 1030 percent and 1385 percent higher than for the chain saw. The productivity of skidding aspen felled by the Dika Side Cutter on sites #1 and 2 was 25 percent and

15 percent higher than for skidding aspen felled by chain saw on sites #1 and 2.

The total costs for harvesting aspen from sites #1 and 2 are summarized in Table 6.

Table 6
Delivered Aspen Costs — Test Method (t)*

Activity	Site #1		Site #2	
	Chain Saw	Dika Side Cutter	Chain Saw	Dika Side Cutter
Felling	\$ 4.30	\$ 0.60	\$ 2.50	\$ 0.60
Skidding	35.00	28.00	10.00	8.75
Loading	5.35	5.35	6.65	6.65
Trucking	11.75	11.75	17.15	17.15
Unloading	1.40	1.40	1.10	1.10
Chipping	12.90	12.90	12.90	12.90
Total Costs	70.70	60.00	50.30	47.15

*Note: oven-dry tonne

Harvesting aspen felled by chain saw on site #2 was 30 percent more cost effective than harvesting aspen by chain saw on site #1. Harvesting aspen felled by the Dika Side Cutter on site #2 was 21 percent more cost effective than harvesting aspen by the Dika Side Cutter on site #1. These figures indicate that tree size was the



Figure 12. Site #1 after full tree harvesting

primary variable in determining unit costs for all phases of the harvesting operation. This finding is typical of all types of harvesting systems.

These production costs could be reduced by altering the configuration of the harvesting system developed and tested on this project. This system consisted of skidding aspen felled by chain saw and Dika Side Cutter to landings where it was cold decked and then loaded for transport to a central storage and chipping site. By eliminating the skidding operation for the aspen felled by the Dika Side Cutter complete mechanization of the system is achieved. This would be made possible by arranging for a log loader to follow behind the Dika Side Cutter and forward the aspen to nearby cold decking areas. By full tree chipping at these cold deck areas the amount of harvesting equipment could be further reduced. A comparison of the estimated costs of this revised method with the costs of harvesting aspen felled by chain saw on sites #1 and 2 is summarized in Table 7.

Generally, the authors of the InterGroup Study felt that approximately \$30/ODt in 1977 dollars was a representative price for large scale wood harvesting operations (InterGroup Consulting Economists, 1978). Based on an annual inflation rate of 10 percent this cost in 1981 dollars would be \$43.92. The costs from the "revised method" in Table 7 are significantly below this range and this

would indicate that they may have reached the level where they may not be an economic burden on a wood gasification project.

Table 7
Delivered Aspen Costs – Revised Method (t)*

Activity	Site #1		Site #2	
	Chain Saw	Dika Side Cutter	Chain Saw	Dika Side Cutter
Felling	\$ 4.30	\$ 0.60	\$ 2.50	\$ 0.60
Skidding	35.00		10.00	
Forwarding		5.35		6.65
Loading	5.35		6.65	
Trucking	11.75	6.73	17.15	7.16
Unloading	1.40		1.10	
Chipping	12.90	8.40	12.90	8.40
Total Costs	70.70	21.08	50.30	22.81

*Note: oven dry tonne

However, the final cost of wood gas from this type of harvesting system will be much higher than merely the delivered aspen costs. One must include the gasification, cleaning and compression costs before the gas could be used in a gas turbine. The best case is site #1 where aspen harvested by the Dika Side Cutter could be delivered at an estimated cost of \$21.08/ODt with a heating value of 19.2×10^3 J/kg. The energy



Figure 13. Site #2 after full tree harvesting

equivalent value of this aspen would be \$1.10/10⁹ J (calculated from Appendix A-3)

The total capital cost of a 64 x 10⁶ J/hr Higher Heating Value (HHV) wet gas fluidized bed gasifier of the B.C. Research type is quoted at \$1,400,000 (Alberta Industrial Developments Ltd., 1980). The annual operating cost not including fuel is estimated to be \$100,000. The life-cycle costs of this unit depreciated over 5 years to a 10 percent residual value at a 15 percent discount rate results in the energy equivalent value of wood gas at the fuel nozzle increasing to \$2.44/10⁹ J (calculated from Appendix A-3). The current Alberta border price for natural gas is \$1.70/10⁹ J (Alberta Petroleum Marketing Commission, September/1981). Therefore on an energy equivalent basis wood gas is seen to be \$0.74/10⁹ J more expensive than natural gas. Based on the September 1981 Ottawa-Alberta energy-pricing and revenue-sharing agreement which established a 5 year pricing regime whereby the price of natural gas will rise every six months by \$0.2563/10⁹ J, it is unlikely that wood gas derived from full tree aspen chips will prove economically competitive with natural gas until 1983.

This conclusion does not reflect possible social and economic benefits that might alter the net cost of using aspen as a source of fuel to generate low Btu gas for gas turbine driven compressors. All direct costs and benefits are important but indirect ones are sometimes equally as important. For example, if harvesting operations reduced site preparation costs for current Alberta Forest Service afforestation programs by \$150/ha, this saving could be added to the value of the aspen chips (A.F.S., 1979). Based on 84.5 OD/t of available material per ha, this cost saving amounts to a \$1.78/ODt. This saving reduces the \$0.74/10⁹ J cost differential between aspen and natural gas to \$0.60/10⁹ J.

Similarly, legislative changes could have a major economic impact. The Alberta border price referred to above does not reflect the border flow back rate that is paid by the Alberta Government to producers under the authority of the Natural Gas Rebates Act. Under this Act, additional revenues from gas exports based on the price difference between the domestic and export price of natural gas are divided among all Alberta gas producers thereby providing an element of equity for those gas producers that are selling at the lower domestic price as opposed to those producers who are selling at the higher export price. This rebate fluctuates but is currently averaging approximately \$0.90/10⁹ J (Alberta Gas

Rebates Branch, 1981). A rebate of this type would eliminate the existing cost differential between wood and natural gas. The Oil and Gas Conservation Act defines "marketable gas" in part as a mixture of methane gas which is recovered at a well from an underground reservoir. Since wood gas is not a "marketable gas" by this definition, it is not eligible for rebates under existing legislation even though its utilization would allow more natural gas to reach the end user. An amendment to this definition would have a dramatic affect on the ability of full tree aspen chips to compete with natural gas.

The average heating value for all aspen samples was 19.2 x 10³ J/kg or 19.2 x 10⁹ J/ODt which is typical of most woods. Moisture and density values were normal and did not vary from site to site. There should be few problems in feeding the aspen chips into a gasifier as they compare favourably with other wood chips.

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Appendix A-1

Average Stand & Stock Table
Site #1
(Number per Hectare)

Diameter (cm)	Aspen Poplar	Balsam Poplar	White Birch	Total
04 - 08	830	0	1468	2299
08 - 12	455	0	191	646
12 - 16	429	41	123	594
16 - 20	86	0	7	93
20 - 24	51	3	0	34
24 - 28	30	3	0	34
TOTAL	1881	47	1789	3700

Average Stand & Stock Table
Site #2
(Number per Hectare)

Diameter (cm)	Aspen Poplar	Balsam Poplar	White Birch	Total
04 - 08	0	0	234	234
08 - 12	0	0	31	31
12 - 16	66	42	10	118
16 - 20	46	41	0	93
20 - 24	98	54	0	152
24 - 28	89	44	0	133
28 - 32	59	11	0	71
TOTAL	358	192	275	832

Average Stand & Stock Table
Site #1
(Volume m³/ha)*

Diameter (cm)	Aspen Poplar	Balsam Poplar	White Birch	Total
04 - 08	18	0	24	42
08 - 12	23	0	9	32
12 - 16	42	3	11	58
16 - 20	15	0	1	17
20 - 24	15	1	0	16
24 - 28	14	1	0	15
TOTAL	127	5	45	183

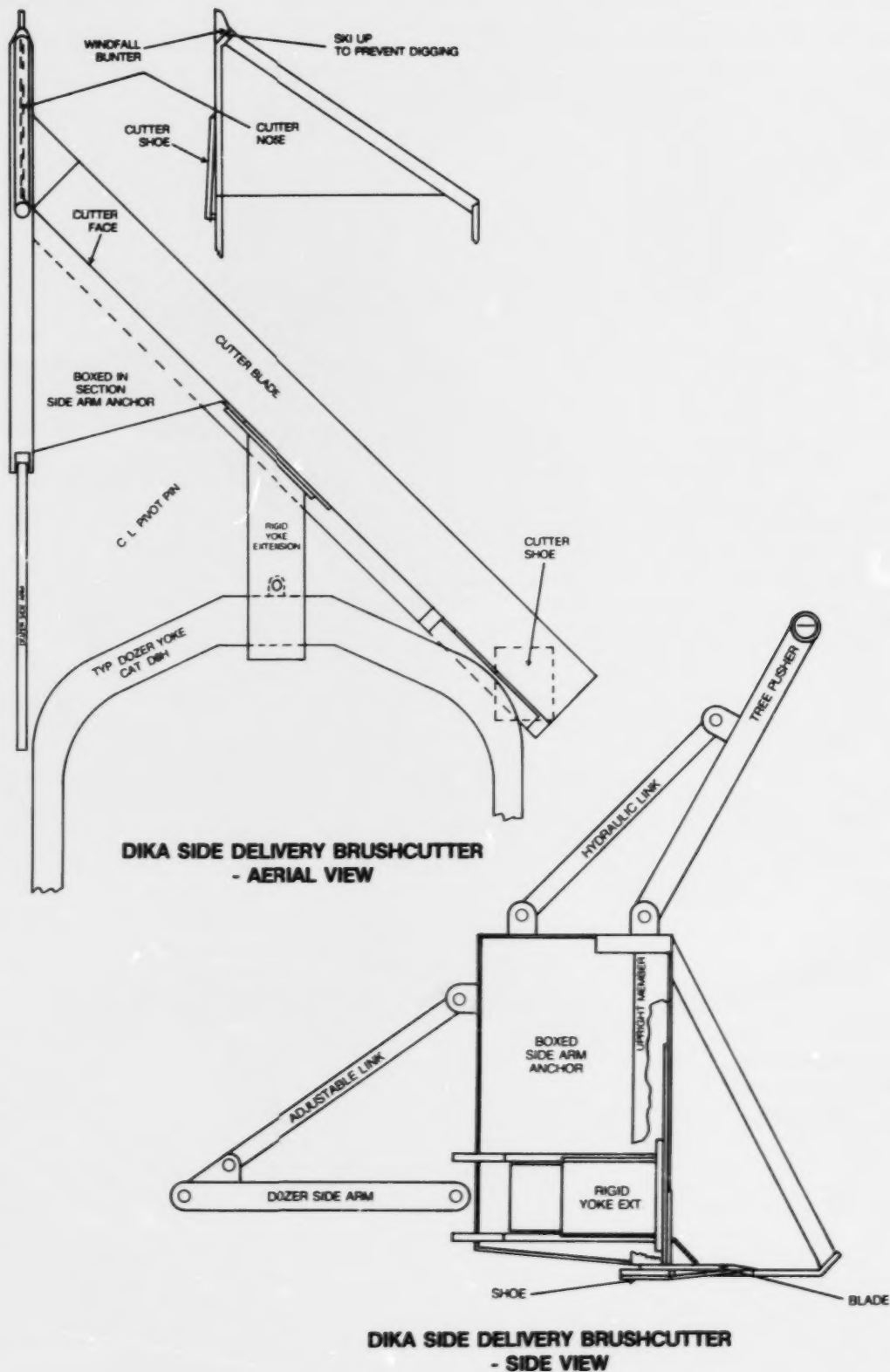
*Note: green weight basis

Average Stand & Stock Table
Site #2
(Volume m³/ha)*

Diameter (cm)	Aspen Poplar	Balsam Poplar	White Birch	Total
04 - 08	0	0	5	5
08 - 12	0	0	1	1
12 - 16	7	5	0	13
16 - 20	8	7	0	17
20 - 24	29	14	0	44
24 - 28	40	19	0	60
28 - 32	44	7	0	51
TOTAL	128	52	6	191

*Note: green weight basis

Appendix A-2



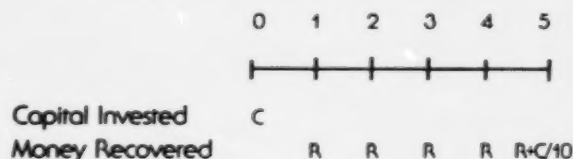
Appendix A-3

Life-Cycle Costing

The comparison of an aspen fuel gasification system with the conventional natural gas energy system presently used for gas turbines requires calculation of all costs over the whole life cycle of the system. In the case of the present report this means determining the present value of the stream of costs involved, over time, of supplying wood gas to gas turbines at pipeline compressor stations.

The energy equivalent value of wood gas at the fuel nozzle is calculated by carrying out standard discounted cash flow techniques. This energy equivalent value is computed as the sum of three components: 1) the cost per green tonne of aspen delivered to the gasification plant converted to cost per oven-dry tonne (ODt); 2) the amortized capital cost of the gasification plant converted to cost per ODt; 3) the operating cost of running the gasification plant converted to cost per ODt.

- (1) If the delivered cost per green tonne of aspen with 46 percent moisture content is \$D, then the equivalent cost per oven-dry tonne is $\$D/.54 = 1.852 \$D$ (i.e. 185.2 green tonnes with 46 percent moisture content become 100 oven-dry tonnes when dehydrated).
- (2) A gasification plant at cost \$C amortized over five years at 15 percent per annum with a residual value of 10 percent of cost would require an annual recovery, R, as set up in the following diagram.



From a present value analysis, the general equation of value is:

$$C = R[1 - (1 + i)^{-n}]/i + C/5 (1 + i)^{-n}$$

where:

- C = Capital cost (\$)
- R = Annual recovery (\$)
- S = Scrap value in year n (percent)
- n = Lifetime of system (years)
- i = Discount rate (percent)

The derived equation of value is:

$$C = R[1 - (1 + .15)^{-5}]/.15 + C/10 (1 + .15)^{-5}$$

or, solving for R,

$$R = [C - C/10 (1 + .15)^{-5}] [1 - (1 + .15)^{-5}]/.15$$

If H is the number of hours per year of operation, the cost per hour is R/H. If, further, the gasification plant is capable of converting T tonnes per hour, the cost per ODt is R/HT.

- (3) Let K be the annual cost of operating the gasification plant. Then as in (2), the cost per ODt is K/HT.

Sample Calculation:

- a) The cost of harvesting aspen felled by the Dika Side Cutter on site #1 using the "Revised Method" was estimated to be \$21.08/ODt. This figure is derived by dividing the hourly rental equipment rate charged by the contractor carrying out each particular phase of the logging and chipping operation by the productivity per Productive Machine Hour (PMH) of the equipment used and multiplying by the ODt factor 1.852 derived in (1).
- b) Converting the cost per ODt to the cost per 10^9 J, 1:19.2, the cost per 10^9 J is $\$21.08/19.2 = \$1.10$.
- c) For a 1.4 million dollar gasification plant ($C = \$1,400,000$), $R = \$396,877.60$. If $H = 8000$ hours and $T = 3.33$ ODt/hr (Derived by dividing 64×10^6 J/hr by 19.2×10^6 J/ODt), then $R/HT = \$14.88$.
- d) For a gasification plant which costs \$100,000 a year to operate, $K/HT = \$3.75$ (same H and T as in b).
- e) The total cost per ODt for wood gas produced from aspen harvested by the "Revised Method" described in a) is $\$21.08 + \$14.88 + \$3.75 = \$39.71$.
- f) Converting the cost per ODt to the cost per 10^9 J, 1:19.2, the cost per 10^9 J is $\$39.71/19.2 = \$2.07$.
- g) Since the gasification plant operates at 85 percent efficiency the equivalent cost of wood gas per 10^9 J at the fuel nozzle is $\$2.07/.85 = \$2.44$.

Note 1: In part (1) inflation was built in to estimating harvesting costs. Part (2) contains no inflation. Hence the only inflationary effects in the total cost will be from part (3). However, since part (3) contributes less than ten percent of the total cost, its inflationary effects can be ignored. The above applies to the first five years only.

Note 2: After five years, the cost in part (2) may be deleted, except for the annual interest on the residual value. This will have the effect of significantly lowering the cost. However, after five years, inflation on part (1) must be taken into account.

*See Freedman, H.I., *Financial Tables*, Wadsworth of Canada, Ltd., 1978, for derivation of general formula.

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